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A Methodology for the Selection of Countermeasures for a Combat Platform Embedded in a System-of-Systems.

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ABSTRACT:

When a combat platform is embedded in a system-of-systems the countermeasures that are appropriate for its protection may be altered from those of an unembedded, stand-alone, platform, since some of the platform's survivability will be assumed by the system-of-systems.

This paper will present a simple, first-cut methodology for determining the following: (1) How much survivability the system-of-systems must contribute so that the survivability of the embedded platform is equal to that of the stand-alone platform it is to replace, and (2) The countermeasures appropriate in order to optimize the survivability of an embedded platform.

INTRODUCTION:

Historically, the combat platform or countermeasure designer has only been interested in optimizing the survivability of a stand-alone platform. This required the selection of a suite of countermeasures that would provide the best protection against the threats most lethal to the platform under consideration. However, if a platform is embedded into a system-of-systems, then the lethality of each individual threat against that platform could be altered, since the system-of-systems into which the platform is embedded will counter at least some portion of at least some of the threats to the platform. But with altered lethalities, the suite of countermeasures required to optimize the platform's survivability might therefore also be altered.

This paper has two goals. The first is to estimate the level of survivability required from the system-of-systems when a heavy combat platform is replaced with a lighter, and therefore supposedly more agile, combat platform. Be clear, however, than no attempt at describing the functioning of the system-of-systems's survivability component is attempted. The second goal of this paper is to determine the threats most lethal to an embedded platform, and thereby to determine the appropriate suite of countermeasures for enhanced survivability.

To accomplish this the methodology will first be outlined. Then

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the methodology will be applied to an extremely simple example for purposes of illustration, and then a more realistic, but still generic, example will be examined. The paper will then conclude as all papers do with a few general remarks.

OUTLINE OF METHODOLOGY:

The methodology outlined in this section makes use of TOSOM-type threat trees. These trees structure the threat according to various categories, beginning with the broadest classification (air, ground, ...) down to the most particular (KE round, ATGM, ...). Each splitting is assigned appropriate percentages, for example, (air: 10%, ground: 90%). The leaves of the tree are thus particular threats, and by following the branches that lead to each threat the probability of encountering that threat can be calculated. For more detail on TOSOM-type threat trees, please see [1].

To begin the process one needs to have a fixed conception of the combat platform to be modeled together with the battlefield environment in which it will be expected to operate. With the platform and environment determined, a TOSOM-type threat tree can then be developed. As already noted, this threat tree provides the probability of encounter.

Next, the probabilities of acquisition, hit, and kill for each threat against the given platform must be determined. With these probabilities determined TOSOM can be run. Note that except for the absence of countermeasures, what has occurred is simply what would occur in a standard TOSOM study.

The outputs of the TOSOM run are an estimate of the platform's survivability, p_{hs}, and the lethality of each threat against the platform. Then from the lethalities of the threats a prioritized list of threats to the platform can be easily obtained.

The next step is to fix the details of the combat platform that will be the replacement for the original combat platform conceptualized above. In general, this new platform will be embedded in a system-of-systems, and will almost certainly be lighter than the platform it is to replace. And as a stand-alone vehicle it will almost certainly be less survivable than the platform it is to replace. This new, replacement, platform will fight in the same threat environment as the original platform, and will therefore make use of the same threat tree, but it will require, considered as a stand-alone platform, new values for the probabilities of acquisition, hit, and kill. It is now possible to rerun TOSOM with the new platform. As before, an estimate of the survivability of the platform, p_{ls}, will be obtained. The difference, $p_{hs} - p_{ls}$, is an estimate for the level of survivability that the system-of-systems will need to provide for

the lighter replacement platform.

For the replacement, lighter, combat platform, postulate a countermeasure, to be provided by the system-of-systems, that defeats with some effectiveness, *e*, those threats that are launched from a distance, *d*, or greater, from the platform. Adjust *e* or *d* or both so that the survivability of the replacement platform with the system-of-systems countermeasure is approximately p_{hs}, the survivability of the original platform.

Finally, considering the replacement platform equipped with the system-of-systems countermeasure to be an integrated combat platform, a TOSOM-type analysis will provide the platform or countermeasure designer with the suite of countermeasures that will optimize the survivability of the integrated platform.

It's worth nothing that since the system-of-systems countermeasure changes the lethalities of the various threats that the platform encounters, the system-of-systems countermeasure may also change the suite of countermeasures required to optimize the platform's survivability.

A VERY SIMPLE EXAMPLE:

The data used in this section and the next are taken from [2].

First, the platform and the battlefield environment need to be specified. The platform is taken to be an approximately 70-ton tank. The battlefield environment is considered to be determined by the threat tree, and the threat tree is given in Table 1.

Direct	85%		
	KE	70%	59.5%
	ATGM	30%	25.5%
Indirect	15%		
	LSAH	100%	15.0%

Table 1: Threat tree (Simple Example)

The three numbers in the right-most column of the threat tree are the probabilities of encountering each of the three threats in this scenario. Next, the probabilities of acquisition, hit, and kill for each threat against the heavy platform must be determined, together with the normal operating range for each threat. This data, from [2], is given in Table 2.

Threat	Normal range (km)	p_e	p_a	p_h	p_k	Lethality
KE	2	.595	1.00	.65	.85	.329

ATGM	4	.255	1.00	.90	.61	.140
LSAH	6+	.150	1.00	.50	.95	.071

Table 2: Threat data (Simple Example, Heavy Platform)

Notice that the right most column in Table 2 can be used to provide a prioritized list of the threats, which in turn can be used to guide the development and integration of countermeasures appropriate to the given platform for the scenario under consideration. Also, the data from Tables 1 and 2 can be used as input to TOSOM where, upon executing the model, it is found that the survivability value for the heavy platform is p_{hs} = .46. This survivability value can also be calculated directly from Table 2; the details of such a calculation can be found in [1].

At this point in the process, the heavy platform is replaced by a lighter platform. For this simple example the lighter platform is taken to be a generic 20-ton combat platform, where the details of such a platform are provided in [2]. For this replacement platform, the threat tree, Table 1, remains the same, but new threat data is required. That is, Table 2 needs to be altered to reflect the lighter platform. This data, from [2], is given in Table 3.

Threat	Normal range (km)	p_e	p_a	p_h	p_k	Lethality
KE	2	.595	1.00	.65	.95	.367
ATGM	4	.255	1.00	.90	.95	.218
LSAH	6+	.150	1.00	.50	.95	.071

Table 3: Threat data (Simple Example, Light Platform)

As above, a TOSOM run or a simple calculation provides the survivability value for the light platform as p_{ls} = .34. Notice that, as expected, the light platform as a stand-alone platform is less survivable than the heavy platform it replaced. Comparing p_{ls} = .34 with p_{hs} = .46 provides an estimate of how much protection the system-of-systems must provide the lighter, replacement platform. The protection to the light platform provided by the system-of-systems will effect threats whose normal operating range is greater than *d* and whose effectiveness upon those threats is *e*. TOSOM is used to determine the survivability value for various values of *d* and *e*. The results are summarized in Table 4.

	d km	*e* %	Survivability
Baseline	7	0	.34
	5	75	.40

	5	99	.41
	3	40	.46
	3	50	.49

Table 4: System-of-systems countermeasure

From Table 4 it is seen that the system-of-systems needs to deploy a countermeasure that will be 40% effective against those threats to the light combat platform that have a normal operating range greater than 3km. If, somehow, the system-of-systems can accomplish that feat, then the light platform will have a survivability value equal to its heavier version. This information is summarized in Table 5.

Threat	Normal range (km)	Lethality no CM	SoS CM effectiveness	Lethality SoS CM
KE	2	.367	0 %	.367
ATGM	4	.218	40 %	.131
LSAH	6+	.071	40 %	.041

Table 5: Light Platform with SoS Countermeasure

Table 5 summarizes the simple example of this section. It informs the countermeasure designer of two critical pieces of information. First, it tells the designer how effective the system-of-systems countermeasure must be and against which threats. Secondly, it offers, via the rightmost column of Table 5, a prioritized list of the threats to the platform. It's worth noting that in this simple example the prioritized list of threats most lethal to the lightweight platform is unaltered by the presence of the system-of-systems countermeasure. That need not be the case in general.

A TYPICAL, GENERIC EXAMPLE:

As mentioned at the beginning of the preceding section, the data used in this section is derived from [2]. The example presented in this section will closely parallel the simple example presented in the preceding section. The difference will be that the number of threats will be greater in order to provide for a more realistic battlefield. The threat tree is given in Table 6.

Direct Fire	85%				
	AFV	54%			
		Tank	22%		
			KE	50%	.050
			HEAT	25%	.025
			AT-11	25%	.025
		IFV	78%		
			KE	80%	.286
			AT-4	20%	.072
	Infantry	46%			

		RPG	75%		.293
		ATGM	18%		
			AT-5	33%	.023
			AT-4	67%	.047
		Towed AT Gun	7%		
			KE	50%	.014
			HEAT	25%	.007
			Missile	25%	.007
Indirect Fire	15%				
	Mortars	40%			
		Dumb	100%		
			HE-Frag	100%	.060
	Artillery	60%			
		Smart	5%		.005
		Dumb	95%		
			HE-Frag	52.5%	.045
			DPICM	47.5%	.041

Table 6: Threat tree

Recall that the numbers in the right-most column of Table 6 are the probabilities of encountering each of the threats listed in the table. Next, the probabilities of acquisition, hit, and kill for each threat against a heavy platform must be determined, together with each threat's normal operating distance. This data, derived from [2], is presented in Table 7.

Threat	Normal range (km)	p_e	p_a	p_h	p_k	Lethality
Tank KE	2	.050	1.00	.65	.85	.028
Tank HEAT	2	.025	1.00	.50	.49	.006
Tank AT-11	5	.025	1.00	.90	.49	.011
IFV KE	2	.286	1.00	.70	.07	.014
IFV AT-4	2	.072	1.00	.90	.49	.032
Inf RPG	.25	.293	1.00	.50	.49	.072
Inf AT-5	3	.023	1.00	.90	.60	.012
Inf AT-4	2	.047	1.00	.90	.49	.021
Inf Gun KE	2	.014	1.00	.55	.85	.007
Inf Gun HEAT	2	.007	1.00	.40	.49	.001
Inf Gun Missile	5	.007	1.00	.85	.49	.003
Mortar HE-Frag	5	.060	1.00	.34	.30	.006
Art Smart	6+	.005	1.00	.50	.95	.002
Art HE-Frag	6+	.045	1.00	.11	.85	.004
Art DPICM	6+	.041	1.00	.30	.95	.012

Table 7: Threat data (Generic Example, Heavy Platform)

As noted in the VERY SIMPLE EXAMPLE section, the right most column in Table 7 can be used to provide a prioritized list of

the threats to the heavy platform in the absence of any system-of-systems countermeasure, which in turn can be used to guide the development and integration of countermeasures appropriate to the given platform for the scenario under consideration. Also, the data from Tables 6 and 7 can be used as input to TOSOM where, upon executing the model, it is found that the survivability value for the heavy platform is p_{hs} = .77. This survivability value can also be calculated directly from Table 7. The details of such a calculation can be found in [1].

The heavy platform is now replaced by a lighter platform. For this generic example the lighter platform is taken to be a generic 20-ton combat platform. The details of such a platform are provided in [2]. For this replacement platform, the threat tree, Table 6, remains the same, but new threat data is required. That is, Table 7 needs to be altered to reflect the lighter platform. This data, again derived from [2], is given in Table 8.

Threat	Normal range (km)	p_e	p_a	p_h	p_k	Lethality
Tank KE	2	.050	1.00	.65	.95	.031
Tank HEAT	2	.025	1.00	.45	.61	.007
Tank AT-11	5	.025	1.00	.90	.95	.021
IFV KE	2	.286	1.00	.60	.45	.077
IFV AT-4	2	.072	1.00	.90	.61	.040
Inf RPG	.25	.293	1.00	.50	.95	.139
Inf AT-5	3	.023	1.00	.90	.95	.020
Inf AT-4	2	.047	1.00	.90	.61	.026
Inf Gun KE	2	.014	1.00	.55	.95	.007
Inf Gun HEAT	2	.007	1.00	.35	.61	.001
Inf Gun Missile	5	.007	1.00	.85	.95	.006
Mortar HE-Frag	5	.060	1.00	.22	.30	.004
Art Smart	6+	.005	1.00	.50	.95	.002
Art HE-Frag	6+	.045	1.00	.07	.85	.003
Art DPICM	6+	.041	1.00	.10	.95	.004

Table 8: Threat data (Generic Example, Light Platform)

As was the case with the heavy platform, a TOSOM run or a simple calculation provides the survivability value for the light platform as p_{ls} = .61. Notice that, as expected, the light platform as a stand-alone platform is less survivable than the heavy platform it replaced.

Comparing p_{ls} = .61 with p_{hs} = .77 provides an estimate of how much protection the system-of-systems must provide the lighter, replacement platform. The protection provided the light platform by the system-of-systems will effect threats whose normal operating range is greater than d and whose effectiveness upon

those threats is *e*. TOSOM is used to determine the survivability value of the light platform for various values of *d* and *e*. The results are summarized in Table 9.

	d km	*e* %	Survivability
Baseline	7	0	.61
	6	95	.62
	5	95	.65
	3	95	.67
	2	95	.85
	2	85	.82
	2	75	.80
	2	65	.77

Table 9: System-of-systems countermeasure

It can be seen from Table 9 that the system-of-systems needs to deploy a countermeasure that will be 65% effective against those threats to the light combat platform that have a normal operating range greater than or equal to 2 km. If, somehow, the system-of-systems can accomplish that feat, then the light platform will have a survivability value equal to its heavier version. This information is summarized in Table 10.

Threat	Normal range (km)	Lethality no CM	SoS CM effectiveness (%)	Lethality SoS CM
Tank KE	2	.031	65	.011
Tank HEAT	2	.007	65	.002
Tank AT-11	5	.021	65	.007
IFV KE	2	.077	65	.027
IFV AT-4	2	.040	65	.014
Inf RPG	.25	.139	0	.139
Inf AT-5	3	.020	65	.007
Inf AT-4	2	.026	65	.009
Inf Gun KE	2	.007	65	.002
Inf Gun HEAT	2	.001	65	.000
Inf Gun Missile	5	.006	65	.002
Mortar HE-Frag	5	.004	65	.001
Art Smart	6+	.002	65	.001
Art HE-Frag	6+	.003	65	.001
Art DPICM	6+	.004	65	.001

Table 10: Light Platform with SoS Countermeasure

Table 10 summarizes the typical, generic example of this section. It informs the countermeasure designer of two critical pieces of information. First, it tells the designer how effective the

system-of-systems countermeasure must be and against which threats. Secondly, it offers, via the rightmost column of Table 10, a prioritized list of the threats to the platform in the presence of the system-of-systems countermeasure. It's worth noting that in this typical example the prioritized list of threats most lethal to the lightweight platform is unaltered by the presence of the system-of-systems countermeasure. That need not be the case in general.

CONCLUSIONS:

In both examples presented in this paper, it was assumed that the system-of-systems countermeasure was uniformly effective against all threats that normally operate beyond a certain range. That assumption is not necessary. It is equally easy to split the threats into range bands and then assume that the system-of-systems countermeasure has a different effectiveness against the threats of each such band.

The method presented above allows the countermeasure designer or integrator to determine whether the threats he or she needs to protect against are altered by the presence of a system-of-systems countermeasure. That is, the method provides a prioritized list of threats both with and without the inclusion of a system-of-systems countermeasure.

The method presented above also allows the platform designer an estimate of which threats and to what degree the system-of-systems countermeasure will provide protection against. What the method does not offer is any indication of how the system-of-systems countermeasure might perform its magic work.

Finally, the method of analysis presented in this paper extends the usefulness of the model TOSOM beyond its use as a simple tool for estimating the survivability of a stand-alone platform.

REFERENCES:

[1] Dave Fredrick, Daniel Hicks, Jack Reed, and William Jackson, *TOSOM Anatomy with Examples*, Proceedings of the Seventh Annual Ground Target Modeling and Validation Conference, August 1996, Michigan Technological University.

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